

END EFFECTOR AND SUBSTRATE TRANSFER SEQUENCE FOR THICK, HEAVY,
AND/OR BOWED SUBSTRATES WITH LIMITED VERTICAL CLEARANCES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No.

5 63/529,498 filed on July 28, 2023. The entire disclosure of the above application is incorporated herein by reference.

FIELD

[0002] The present disclosure relates to substrate processing systems, and more particularly to an end effector and a substrate transfer sequence for thick, heavy, and/or

10 bowed substrates.

BACKGROUND

[0003] The background description provided here is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description
15 that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

[0004] Substrate processing systems are typically used to treat substrates such as semiconductor wafers. For example, the substrate processing systems can be used to deposit thin film on the substrate, etch thin film on the substrate, clean a surface of the
20 substrate, and/or perform other treatments. Different types of processing chambers are used depending on the type of substrate treatment to be performed. During deposition, a substrate is delivered to the processing chamber and deposition process gases are supplied by a gas delivery system to the processing chamber. During etching, the substrate is delivered to the processing chamber and etching process gases are
25 supplied by a gas delivery system to the processing chamber. During both etching and deposition, plasma may be used to enhance chemical reactions.

[0005] The design of the processing chamber is typically optimized for a given substrate treatment and physical characteristics of the substrates to be processed. In some substrate treatments, clearance between a top surface of the substrate and a
30 bottom surface of a showerhead, a dielectric window, or other chamber structure is

minimized to enhance the effectiveness of the substrate treatment. Minimizing these dimensions poses constraints on a substrate transfer sequence, dimensions of an end effector, movement of the lift pins, a height of an edge ring, etc.

5 [0006] The dimensions of the processing chamber are typically specified in view of substrates that are within a predetermined or standard substrate weight, thickness, and/or bowing ranges. Problems arise when the processing chamber is used to treat non-standard substrates that are heavier, thicker, and/or have more pronounced bowing than the standard substrates. In other words, the non-standard substrates cannot be delivered to the substrate support without contacting lift pins, an edge ring, 10 an opening of a chamber liner slot, or other structures in the processing chamber. As a result, the non-standard substrates need to be processed in another type of processing chamber, which increases cost.

SUMMARY

15 [0007] An end effector for a substrate processing system includes a body including a first body portion configured to connect to a wrist of a robot; a second body portion extending from the first body portion and including a first arm, a second arm, and a slot between the first arm and the second arm; and a plurality of contact pads. The plurality of contact pads include N contact pads arranged on the second body portion adjacent to the first body portion, where N is an integer greater than two; M contact pads 20 arranged on distal ends of the first arm and the second arm, respectively, where M is an integer greater than one; P contact pads, where P is an integer greater than one; and Q contact pads, where Q is an integer greater than one. The P contact pads and the Q contact pads are located on the first arm and the second arm between the N contact pads and the M contact pads.

25 [0008] In other features, the body includes (N+M+P+Q) cavities for receiving the plurality of contact pads. The N contact pads, the M contact pads, the P contact pads, and the Q contact pads are made of elastomer. The end effector is made of one or more materials comprising alumina (Al₂O₃), sapphire (Al₂O₃), silicon carbide (SiC), silicon nitride (SiN), aluminum nitride (AlN), graphite, and molybdenum (Mo). The end 30 effector is made of alumina (Al₂O₃).

[0009] In other features, N = 3 and the N contact pads are spaced evenly from one another on the second body portion.

[0010] In other features, $N = 4$ and the N contact pads are spaced evenly from one another on the second body portion.

[0011] In other features, the end effector has a thickness in a range from 0.070" to 0.090". A height of the N contact pads and the M contact pads is greater than a height
5 of the P contact pads and the Q contact pads.

[0012] In other features, a height of the N contact pads and the M contact pads is in range from 0.015" to 0.060". The height of the P contact pads and the Q contact pads is in range from 0.010" to 0.040". The height of the N contact pads and the M contact pads is greater than the height of the P contact pads and the Q contact pads.

10 [0013] In other features, the P contact pads and the Q contact pads are arranged along a circle having a first radius and the N contact pads and the M contact pads are arranged along a circle having a second radius that is greater than the first radius. A third radius of a substrate supported by the end effector is greater than the first radius and the second radius. The first body portion has a first thickness, and the second body
15 portion has a second thickness less than the first thickness.

[0014] A substrate delivery system for a substrate processing chamber includes a robot including a wrist. An end effector is connected to the wrist and including a body, a first arm and a second arm extending from the body, and a plurality of contact pads configured to support a substrate above the body. Lift pins are configured to extend
20 above the substrate support and to retract. A processing chamber includes a chamber port. A controller is configured to perform a first transfer sequence to deliver the substrate onto the substrate support. The first transfer sequence includes causing the robot to load the substrate onto the end effector; with the lift pins retracted, causing the robot to pass the substrate and the end effector through the chamber port to a location
25 above the substrate support; causing the lift pins to extend; causing the end effector to lower the substrate onto the lift pins; and causing the robot to withdraw the end effector through the chamber port.

[0015] In other features, the processing chamber further includes a chamber liner including a chamber liner slot. The controller is configured to pass the substrate and the
30 end effector through the chamber port and the chamber liner slot to the location above the substrate support; and remove the end effector through the chamber port and the chamber liner slot.

[0016] In other features, the controller is further configured to perform a second transfer sequence to retrieve a substrate from the substrate support. The second transfer sequence includes causing the lift pins to extend to raise the substrate above the substrate support; causing the robot to move the end effector between the substrate support and the substrate; causing the robot to raise the end effector; causing the lift pins to be lowered; and causing the robot to remove the substrate through the chamber port.

[0017] In other features, the body of the end effector includes a first body portion configured to connect to the wrist; and a second body portion extending from the first body portion and including the first arm, the second arm, and a slot between the first arm and the second arm. The plurality of contact pads include N contact pads arranged on the second body portion adjacent to the first body portion, where N is an integer greater than two; M contact pads arranged on distal ends of the first arm and the second arm, respectively, where M is an integer greater than one; P contact pads, where P is an integer greater than one; and Q contact pads, where Q is an integer greater than one. The P contact pads and the Q contact pads are located on the first arm and the second arm between the N contact pads and the M contact pads.

[0018] In other features, the body includes $(N+M+P+Q)$ cavities for receiving the contact pads. The N contact pads, the M contact pads, the P contact pads, and the Q contact pads are made of elastomer. The end effector is made of one or more materials comprising of alumina (Al_2O_3), sapphire (Al_2O_3), silicon carbide (SiC), silicon nitride (SiN), aluminum nitride (AlN), graphite, and molybdenum (Mo). The end effector is made of alumina (Al_2O_3).

[0019] In other features, $N = 3$ and the N contact pads are spaced evenly from one another on the second body portion.

[0020] In other features, $N = 4$ and the N contact pads are spaced evenly from one another on the second body portion. The end effector has a thickness in a range from 0.070" to 0.090".

[0021] In other features, a height of the N contact pads and the M contact pads is greater than a height of the P contact pads and the Q contact pads.

[0022] In other features, a height of the N contact pads and the M contact pads is in range from 0.015" to 0.060". The height of the P contact pads and the Q contact pads is

in range from 0.010" to 0.040". The height of the N contact pads and the M contact pads is greater than the height of the P contact pads and the Q contact pads.

5 [0023] In other features, the P contact pads and the Q contact pads are arranged along a circle having a first radius and the N contact pads and the M contact pads are arranged along a circle having a second radius that is greater than the first radius. A third radius of a substrate supported by the end effector is greater than the first radius and the second radius.

[0024] In other features, the first body portion has a first thickness, and the second body portion has a second thickness less than the first thickness.

10 [0025] Further areas of applicability of the present disclosure will become apparent from the detailed description, the claims, and the drawings. The detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

15 [0026] The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0027] FIG. 1A is a functional block diagram of an example of a processing chamber for treating substrates according to the present disclosure;

20 [0028] FIG. 1B is a perspective view of a substrate support, a chamber liner with a slot, and a chamber port according to the present disclosure;

[0029] FIG. 1C is a perspective view of the substrate support, the chamber liner with the slot, the chamber port, and an end effector connected to a robot wrist according to the present disclosure;

25 [0030] FIG. 2 is a simplified cross sectional view of an example of an end effector delivering a standard substrate with minimal or no bowing to a processing chamber;

[0031] FIGS. 3A to 3D show examples of various types of bowing of non-standard substrates;

[0032] FIG. 4 is a simplified cross sectional view of an example of an end effector delivering a non-standard substrate to a processing chamber;

[0033] FIGS. 5A to 5D illustrate steps of an example of a substrate transfer sequence for delivering a non-standard substrate to a processing chamber with restricted clearance according to the present disclosure;

5 [0034] FIG. 6 is a flowchart of an example of a method for delivering a non-standard substrate to a processing chamber according to the present disclosure;

[0035] FIG. 7A is a plan view illustrating an example of an end effector including contact pads according to the present disclosure;

[0036] FIG. 7B is a side cross section of an example of a contact pad; and

10 [0037] FIGS. 7C to 7E are plan views illustrating examples of end effectors including contact pads according to the present disclosure.

[0038] In the drawings, reference numbers may be reused to identify similar and/or identical elements.

DETAILED DESCRIPTION

15 [0039] A substrate processing system may be optimized for standard substrates (such as silicon substrates) having standard weight, thickness, and/or bowing ranges. The dimensions of the substrate processing system may be specified with relatively tight tolerances for processing the standard substrates. When the processing chamber is used for a non-standard substrate (e.g., thicker, heavier, and/or more bowed than standard substrates) clearance problems may arise. In some examples, the substrates
20 may be approximately 2 to 5 times the standard weight, 1.5 to 3 times the standard thickness, and have up to +/-4mm of bow (e.g., +/-2mm of bow).

[0040] Due to the increased weight/deformation, the non-standard substrates cause increased deflection of the end effector (e.g., 2 to 5 times standard deflection). The deflection increases a swept volume above and below a standard swept volume during
25 robot motion. Swept volume refers to a volume through which the end effector, robot wrist and/or substrate move during substrate transfer/ Swept volume needs to be clear from obstruction or collision will occur. Existing robots/end effectors and/or processing chamber designs may not provide sufficient vertical clearance to allow handling of the non-standard substrates using existing transfer sequences, robots, end effectors,
30 and/or contact pad arrangements.

[0041] Substrate transfer sequences performed by the robots include z-axis transfer (or Z-transfer) and single plane transfer. When using Z-transfer, the lift pins are extended and the robot/end effector moves the substrate into the processing chamber over the extended lift pins. When the robot/end effector is positioned correctly in the processing chamber, the robot/end effector moves in a downward direction (e.g., in the z-axis) to transfer the substrate onto the lift pins. The robot/end effector retracts out of the processing chamber. A Z-transfer pickup reverses these steps.

[0042] When using single plane transfer, the robot/end effector places the substrate in coordination with movement of the lift pins. In other words, the robot/end effector moves the substrate into the processing chamber with the lift pins in a retracted position. The lift pins are extended to lift the substrate above the end effector. Then, the robot/end effector retracts out of the processing chamber. A single plane transfer pickup reverses these steps.

[0043] For single plane transfers, the robot/end effector moves in and out of the processing chamber at one height with no z-axis motion inside of the processing chamber. This approach reduces the total vertical clearance needed by the robot/end effector to perform the transfer. The single plane transfer trades increased execution time (due to coordination of the robot and lift pin motion) in exchange for reduced vertical clearance.

[0044] Given the tight dimensions, a thickness of the end effector is optimized for the standard substrates. The end effector is typically made of stainless steel. The end effector cannot be too thin since the weight of the substrate payload on the end effector causes deflection. The deflection adds to vertical clearance that is required. Deflection also limits edge ring height when using a single plane transfer as compared to Z-transfer. In other words, the payload deflection of the end effector when using Z-transfer occurs while the end effector is higher above the extended lift pins where deflection does not impact edge ring height.

[0045] Transferring non-standard substrates may not be possible with existing end effectors and substrate transfer sequences due to the available vertical clearance dimensions of the processing chamber. For example, when using Z-transfer, there may be insufficient clearance to move the substrate into the processing chamber over the lift pins while clearing an upper edge of the opening in the chamber liner. When the substrate is located on the lift pins, the downward bow in the substrate may require the

end effector to be moved lower further reducing the clearance between the end effector and the edge ring. It may not be possible to reduce deflection by making the end effector thicker (to counter payload deflection) without significantly limiting the height of the edge ring. If single plane transfer is used, issues with obstruction of the upper edge of the chamber liner slot are mitigated. However, the edge ring height is severely restricted by the lift pin height and the end effector may contact the substrate support due to substrate induced deflection of the end effector.

[0046] To alleviate the clearance issues noted above, an end effector and a substrate transfer sequence according to the present disclosure allow a processing chamber (with tight dimensions for standard substrates) to be used for non-standard substrate dimensions that are thicker, heavier, and/or have increased bowing. The substrate transfer sequence according to the present disclosure includes a hybrid of Z-transfer and single plane motion.

[0047] During the hybrid substrate transfer, the substrate is moved into the processing chamber with the lift pins in a retracted position. This allows the substrate to move into the processing chamber at a reduced height that allows the substrate to clear the upper edge of the chamber liner slot without risk of collision with the extended lift pins.

[0048] The move in height can occur at a position high enough that payload deflection does not restrict the edge ring height. Once the end effector is in position, the lift pins are extended, and the robot moves downwardly to transfer the substrate from the end effector to the lift pins. The end effector retracts out of the processing chamber from under the substrate. The lift pins lower the substrate onto the substrate support.

[0049] Substrates that bow in a downward direction while sitting on the lift pins restrict edge ring height. However, the restriction on edge ring height is less than pure single plane transfer movement. Additional clearance is provided by reducing deflection of the end effector using stiffer materials than stainless steel.

[0050] The end effector includes additional contact pads that are located to support the substrate under different bow conditions. Contact pads near the center of the end effector support a bowl-shaped substrate while contact pads closer to the substrate edge support a dome-shaped substrate. Half-pipe and saddle bowed and warped substrates rest on a mixture of radially inner and outer pads.

[0051] The hybrid transfer sequence avoids or limits the need to enlarge the height of the chamber liner slot or other openings (e.g., slot valve, chamber body) for substrate transfer. When combined with an end effector that biases the substrate bow upwards from a nominal support plane, the vertical clearance required between the substrate on the lift pins and the edge ring is minimized. This enables a greater edge ring height range for a specific lift pin height, and greater range for tuning of plasma effects at the edge of the substrate.

[0052] Referring now to FIG. 1A, an example of a substrate processing system 10 utilizing the end effector and substrate transfer sequence according to the present disclosure are shown. While a specific type of substrate processing system is shown for purposes of illustration, other types of substrate processing systems may be used.

[0053] The substrate processing system 10 includes a processing chamber 18. The processing chamber 18 further comprises a substrate support (or pedestal) 20 for supporting a substrate 32. The substrate support 20 may include an electrostatic chuck (ESC), or a mechanical chuck or other type of chuck. In some examples, the substrate support 20 includes a baseplate 22 including cooling channels 24, a bonding layer 28 and a top plate 26. An edge ring 34 is arranged around the substrate support 20. The top plate 26 may include resistive heaters for heating the substrate and/or conductors for electrostatically clamping the substrate 32.

[0054] The processing chamber 18 includes a chamber port 37, a chamber door 38, and an actuator 39 for selectively moving the chamber door 38 to open and close the chamber port 37. A chamber liner 33 surrounds the substrate support 20 and includes a slot 35 is arranged near and aligned with the chamber port 37 to allow substrates to be delivered and removed. In some examples, the chamber port 37 of the processing chamber 18 is attached to a vacuum transfer module (not shown).

[0055] Process gas is supplied to the processing chamber 18 and plasma 40 may be generated inside of the processing chamber 18 during substrate treatment such as deposition or etching. If plasma is used, the substrate processing system 10 includes an RF plasma generator 50. In some examples, the RF plasma generator 50 includes an RF source 52, a pulsing circuit 54, and a tuning circuit 58. The pulsing circuit 54 controls an envelope of the RF signal and varies a duty cycle of envelope during operation. As can be appreciated, the pulsing circuit 54 and the RF source 52 can be combined or separate.

5 [0056] The tuning circuit 58 may be directly connected to one or more coils 64. In some examples, a single inductive coil is used. In other examples, multiple inductive coils each including one or more conductors are used. The tuning circuit 58 tunes an output of the RF source 52 to a desired frequency and/or a desired phase, matches an impedance of the coils 64, and/or splits power between the coils 64.

[0057] In some examples, a plenum 44 may be arranged between the coils 64 and a dielectric window 42 to control the temperature of the dielectric window 42 with hot and/or cold gas (e.g., air) flow. The dielectric window 42 is arranged along one side of the processing chamber.

10 [0058] A gas delivery system 70 may be used to supply process gas mixtures to the processing chamber 18. The gas delivery system 70 may include process, carrier, and/or inert gas sources 72, a gas metering system 74 (such as valves and mass flow controllers), and a manifold 76 for mixing the gases. A gas delivery system 80 may be used to deliver gas 82 via a valve 81 to the plenum 44. The gas may include cooling
15 gas (e.g., air) that is used to cool the coils 64 and the dielectric window 42.

[0059] A temperature controller 110 may be used to control heating/cooling of the substrate support 20 to a predetermined temperature. For example, the temperature controller 110 may be used to control resistive heaters in the top plate 26 and/or flow of cooling fluid to the cooling channels 24.

20 [0060] An exhaust system 90 includes a valve 92 and pump 94 to control pressure within the processing chamber 18 and/or to remove reactants from the processing chamber 18 by purging or evacuation. An RF bias generator 120 includes one or more RF sources 124, a pulsing circuit 128, and a bias matching circuit 132 to selectively provide an RF bias to the substrate support 20 if needed.

25 [0061] A robot 140 including an end effector 142 performs a hybrid substrate transfer sequence as will be described further below to deliver the substrate 32 to the processing chamber 18 for processing and to remove the substrate 32 from the processing chamber 18 after processing. A controller 150 may be used to control the etching process. The controller 150 monitors system parameters and controls delivery
30 of the gas mixture, striking, maintaining, and/or extinguishing the plasma (if used), the RF bias (if used), substrate temperature, removal of reactants, supply of cooling gas, pressure, and so on. The controller 150 may also be used to control the actuator 39 for the chamber port 37 and the robot 140.

[0062] Referring now to FIG. 1B and 1C, an example of a processing chamber with a chamber liner having a chamber liner slot is shown. In FIG. 1B, an upper surface 200 of a substrate support is surrounded by an edge ring 210. A chamber liner 220 includes spaced openings 222 and a chamber liner slot 221 including an outer slot zone 224, a middle slot zone 226, and an inner slot zone 227. In some examples, the outer slot zone 224 may be vertically narrower than the middle slot zone 226. In some examples, the middle slot zone 226 may be vertically narrower than the inner slot zone 227.

[0063] The inner slot zone 227 includes a lower edge 228 and an upper edge 229. An inner surface 230 of the processing chamber includes a chamber port 232. As will be described further below, a robot/end effector moves the substrate into the processing chamber through the chamber port 232 and the chamber liner slot 221.

[0064] In FIG. 1C, a wrist 250 of the robot includes a first mounting fixture 252 including one or more fasteners 254 for connecting the first mounting fixture 252 to a second mounting fixture 260. One or more fasteners 264 connect the second mounting fixture 260 to an end effector 270. The end effector 270 includes one or more contact pads 272 extending above the surface of the end effector 270.

[0065] Referring now to FIG. 2, upper and lower edges 310 and 312 of a chamber liner slot 316 are shown. A wrist 319 and an end effector 320 including contact pads 328 support a substrate 334 during a Z-transfer. Pins 352 are extended before the end effector 320 delivers the substrate 334 to a position above a substrate support 348 and an edge ring 344. Since the substrate 334 is a standard substrate, clearance between the upper edge 310 and an upper edge of the lift pins 352 is less constrained as compared to non-standard substrates.

[0066] The substrate 334 is delivered onto the substrate support 348 without the substrate 334, the end effector 320, or the wrist 319 contacting any component of the processing chamber. Chamber liner slot 316 defines narrow openings through which the substrate needs to be delivered and picked up. In FIG. 2, a dimension **A** is shown between a lower surface of the end effector 320 and an upper surface of the edge ring 344. A dimension **B** is shown between an upper surface of the substrate 334 and an upper edge of the chamber liner slot 316. A dimension **C** is shown between a lower surface of the substrate 334 and a lower edge of the chamber liner slot 316. A dimension **D** is shown between a lower edge of the wrist 319 to the lower edge of the chamber liner slot 316. Some of these dimensions may have negative values

(corresponding to insufficient clearance) when non-standard substrates are used (unless the end effector and/or the substrate transfer sequence described herein are used).

5 [0067] Referring now to FIGS. 3A to 3D, various examples of substrate bowing are shown. In FIG. 3A, a substrate 334-1 is shown with umbrella-shaped bowing (e.g., spherical bowing in an upward direction). In FIG. 3B, a substrate 334-2 is shown with bowl-shaped bowing (e.g., 2mm of spherical bow in a downward direction). Other types of bowing include half-pipe or chip-shaped bowing. In FIG. 3C, a substrate 334-3 is shown with half-pipe-shaped bowing (e.g., including bowing up or down on one axis). In 10 FIG. 3D, a substrate 334-4 is shown with chip-shaped bowing (e.g., spherical curvature in opposite directions on orthogonal axes).

[0068] In addition to bowing, the weight of the substrate may be about 2x to 5x times the nominal weight of the substrate (e.g., in some examples, the nominal weight is about 100g to 150g (e.g., 125g)) and the thickness of the substrate may be about 1.5x 15 to 3x the nominal thickness of the substrate (e.g., the nominal thickness is in a range from 700 μm to 900 μm (e.g., 800 μm)). The increased weight of the non-standard substrate causes increased deflection of the end effector and therefore requires more vertical clearance to move the non-standard substrate in and out of the processing chamber.

20 [0069] Referring now to FIG. 4, when a non-standard substrate is processed, the bowing of the substrate (in addition to deflection of the end effector) may be greater than the available clearance to the edge ring, chamber liner slot, or other structures (e.g., dimensions **A**, **B**, **C** and/or **D** shown above). With these tight dimensions, the weight, thickness, or bowing of the non-standard substrate may prevent the non- 25 standard substrate from being processed in the processing chamber.

[0070] Referring now to FIGS. 5A to 5D, a wafer transfer sequence according to the present disclosure is shown. In FIG. 5A, with the lift pins 352 retracted, the wrist 319 and the end effector 320 move a substrate 334' (e.g., a non-standard substrate) into the processing chamber through the chamber liner slot 326 above the edge ring 344. In 30 FIGS. 5B and 5C, when the end effector 320 is located over the substrate support 348 (after clearing the chamber liner slot 316), the lift pins 352 are extended and the end effector 320 is retracted to lift the substrate 344' above the end effector 320. In FIG. 5D, the end effector 320 is retracted from the processing chamber. Then, the substrate 344'

is lowered by the lift pins 352 onto the substrate support 348. The process is reversed when picking up the substrate 344'.

[0071] To provide context, examples of dimensions **A**, **B**, **C**, and **D** (shown in FIG. 4) are provided for an example processing chamber when the end effector and hybrid transfer sequence of FIGS. 5A to 5D are used with a non-standard substrate. Note that using the Z-transfer or single plane transfer with the non-standard substrate was not possible due to obstruction by upper and lower edges of the chamber liner slot and/or the edge ring. In some examples, a root sum squared (RSS) toleranced value for dimension **A** is in a range from 0.025" to 0.14" (e.g., 0.070"). In some examples, the RSS toleranced value for dimension **B** is in a range from 0.010" to 0.090" (e.g., 0.050"). In some examples, the RSS toleranced value for dimension **C** is in a range from 0.025" to 0.13" (e.g., 0.065"). In some examples, the RSS toleranced value for dimension **D** is in a range from 0.12" to 0.24" (e.g., 0.181").

[0072] Referring now to FIG. 6, a method 400 for performing a substrate transfer sequence for a non-standard substrate is shown. At 410, the substrate is loaded onto end effector. At 414, the end effector and the substrate pass through the chamber port and the chamber liner slot with the lift pins in a retracted position. The end effector is at a height to allow the substrate to clear the upper edge of chamber liner slot. At 418, the lift pins are moved to an extended position to raise the substrate above the end effector and the end effector is moved in a downward direction at 422. In some examples, movement of the lift pins and the robot overlap or are sequential in time.

[0073] At 426, the end effector is removed from the processing chamber through the chamber liner slot. At 430, the lift pins are retracted to rest the substrate on the substrate support and the processing of the substrate can begin. At 434, the method determines whether the process is finished. If 434 is false, the method returns to 434. If 434 is true, the method continues at 440.

[0074] When the treatment is finished, the lift pins are moved to an extended position at 440 to raise substrate over substrate support. At 444, the end effector is inserted through chamber liner slot and the chamber port to a location between the substrate and the substrate support. At 448, the end effector is moved upwardly to raise the substrate off of the lift pins. At 452, the lift pins are moved to a retracted position. In some examples, movement of the lift pins and the robot overlap or are sequential in time.

[0075] At 456, the robot/end effector is retracted through the chamber liner slot and the chamber port. At 460, the method determines whether another substrate is to be processed. If 460 is true, the method returns to 410. Otherwise, the method ends.

[0076] Referring now to FIGS. 7A to 7D, various examples of end effectors are shown with different patterns of contact pads to handle both standard and non-standard substrates. In FIG. 7A, an end effector 500 includes a body 510. A sloped edge 514 of the end effector 500 transitions downwardly from a first body portion 515 having a first thickness to a second body portion 517 having a second thickness less than the first thickness. In some examples, the end effector 500 includes elongate slots 512 that are arranged along an edge of the first body portion to receive fasteners to connect the end effector to the wrist. In some examples, a difference between the first thickness and the second thickness is approximately equal to a height of adjacent contact pads (e.g., contact pads 540 described below).

[0077] A substrate 518 having a radius R is supported on a plurality of contact pads 540, 542, 544, and 548 above the second body portion 517. The second body portion 517 includes a slot 524 extending between a first arm 520 and a second arm 522. In some examples, the slot 524 is bottle shaped. In some examples, the slot 524 provides clearance for one or more lift pins during substrate transfer (e.g., allowing the lift pins to be extended while the end effector is inserted and removed from the processing chamber).

[0078] In some examples, the first body portion 515 is connected to a wrist of the robot. The first arm 520 and the second arm 522 extend from the second body portion 517. The slot 524 includes a first slot portion 525 having a rounded rectangular shape and a second slot portion 527 having a rounded trapezoidal shape. The first slot portion 525 is narrower in a first direction (perpendicular to a longitudinal direction of the end effector) as compared to the second slot portion 527.

[0079] The end effector 500 includes the set of contact pads 540, 542, 544, and 548 arranged in a pattern to support different contact locations of the standard and non-standard substrates. N of the contact pads 540 and M of the contact pads 548 are located on opposite sides of the substrate 518 near a radially outer edge of the substrate, where N is an integer greater than two and M is an integer greater than one. The N contact pads 540 are located adjacent to and radially inward from the sloped edge 514. The M contact pads 548 are located near distal ends of the first and second

arms 520 and 522. In some examples, the N contact pads 540 and the M contact pads 548 are located at approximately the same radial distance r_2 from a center point 529 of a substrate 518 when the substrate 518 is arranged on the end effector 500.

5 [0080] P of the contact pads 542 and Q of the contact pads 544 are located near middle portions of the substrate 518, where P and Q are integers greater than one. In some examples, the P contact pads 542 and the Q contact pads 544 are located at approximately the same radial distance r_1 from the center point 529 of the substrate 518 when the substrate 518 is on the end effector 500. In some examples, the N contact pads 540 are evenly spaced from one another. As used herein, approximately
10 means within +/- 5%. In the example in FIG. 7A, N is equal to 3, and M, P and Q are equal to 2.

[0081] Increasing the number of contact pads on the end effector 500 (e.g., from 4 contact pads (located near edges of the substrate support) to 9 contact pads shown in FIG. 7A) improves protection of the non-standard substrates. For example, the P
15 contact pads 542 and the Q contact pads 544 are positioned and configured to prevent bowl-shaped substrates from contacting the end effector 500. The N contact pads 540 and the M contact pads 548 are positioned and configured to prevent umbrella-shaped substrates from contacting the end effector. While fewer taller contact pads can be used, using taller contact pads requires the thickness of the edge ring to be reduced
20 and/or the thickness of the end effector to be reduced).

[0082] In some examples, the end effector 500 has a thickness in a range from 0.070" to 0.090" (e.g., 0.080"). In some examples, the P contact pads 542 and the Q contact pads 544 (e.g., radially inner contact pads) have a height in range from 0.010" to 0.040" (e.g., 0.020"). In some examples, the N contact pads 540 and the M contact pads 548
25 (e.g., radially outer contact pads) have a height in range from 0.015" to 0.060" (e.g., 0.030"). In other words, the outer contact pads are thicker than the inner contact pads in the z-axis direction. In some examples, the height of inner contact pads above the end effector is in a range from 25% to 100% of the height of the outer contact pads.

[0083] In some examples, the plurality of contact pads 540, 542, 544, and 548 are
30 made of the same material as and are integrated with the end effector 500. In other examples, the contact pads 540, 542, 544, and 548 are made of a different material than the end effector 500. In some examples, the plurality of contact pads 540, 542,

544, and 548 are made of a chemically resistant, durable, and flexible material such as elastomer.

[0084] In some examples, the contact pads 542 and 544 are located on an outer circumference of a reference circle with radius $r1$ that is concentric with a diameter of the substrate 518 when loaded where the radius $r1$ is less than or equal to 35%, 40%, 45%, or 50% of the radius R of the substrate 518. In some examples, the contact pads 540 and 548 are located on an outer circumference of a reference circle with radius $r2$ that is concentric with the substrate 518 when loaded where the radius $r2$ is greater than or equal to 75%, 80%, 85%, or 90% of the radius of the substrate 518.

[0085] In FIG. 7B, an example of a contact pad 550 is shown. The contact pad 550 includes a head portion 552 and a stem portion 553 extending from the head portion 552. In this example, the head portion 552 of the contact pad 550 has a circular cross section in a plan view (side view shown in FIG. 7B). The stem portion 553 includes a cavity 555 extending in the z-axis direction. The head portion 552 includes a first flanged portion 554 extending radially outwardly from one end of the stem portion 553. A second flanged portion 558 extends radially outwardly from an opposite end of the stem portion 553.

[0086] The body 510 of the end effector 500 includes cavities 570 that pass through the end effector 500 in the z-axis direction to removably receive portions of the contact pads 550. An upper end of the cavity 570 includes a flange 574 that extends radially inwardly into the cavity 570 from a radially inner surface of the cavity 570. During insertion of the contact pad 550 into the cavity 570, the second flanged portion 558 is forced into the cavity 570 through an opening 571 in the flange 574 to a location below the flange 574 to retain the contact pad 550 in place during use.

[0087] In some examples, the first flanged portion 554 and the second flanged portion 558 of the contact pad 550 have diameters greater than a diameter of the opening 571 in the flange 574. In some examples, the first flanged portion 554 has a diameter greater than the second flanged portion 558. The first flanged portion 554 has a diameter greater than the diameter of the cavities 570. The second flanged portion 558 has a diameter greater than the diameter of the opening 571 and less than the diameter of the cavities 570. The stem portion 553 has a diameter less than or equal to the opening 571.

[0088] In FIG. 7C, an end effector 578 includes with $N = 4$ of the contact pads 540. In some examples, the N contact pads 540 are evenly spaced from one another along a circumferential line at the radius $r2$. As can be appreciated, additional contact pads ($N = 5$ or greater) can be used.

5 [0089] In FIG. 7D, an end effector 580 includes an arcuate contact pad 540A instead of the N contact pads 540 in FIGS 7A and 7C. The arcuate contact pad 540A includes an arcuate shaped upper portion 782 as shown in FIG. 7D. In some examples, a side cross section (e.g., transverse to the circumferential line including the arcuate shaped upper portion) is similar to the cross section shown in FIG. 7B.

10 [0090] As can be appreciated, the values of $r1$ and $r2$ can be changed relative to R . In FIG. 7E, $r1' > r1$. Outer pads (at radius $r2$) are generally set close to the radially outer edge of the substrate with a setback for potential wafer offset during transfers plus any edge exclusion requirement. Inner pads (at radius $r1$) are set to support a bowl-shaped substrate to biasing the bow above a plane defined by the pad. In some examples, the
15 inner pads are arranged at or slightly below the outer pad height for best support of a flat wafer.

[0091] In some examples, the end effector is made of a stiffer material than stainless steel. In some examples, the end effector is made of a material selected from a group consisting of alumina (Al_2O_3), sapphire (Al_2O_3), silicon carbide (SiC), silicon nitride
20 (SiN), aluminum nitride (AlN), graphite, and molybdenum (Mo). The added stiffness of the end effector reduces deflection of the end effector due to the increased weight of the substrate (without thickening of the end effector). In other examples, the end effector is thickened instead of or in addition to using a stiffer material.

[0092] The foregoing description is merely illustrative in nature and is in no way
25 intended to limit the disclosure, its application, or uses. The broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent upon a study of the drawings, the specification, and the following claims. It should be understood that one or more steps
30 within a method may be executed in different order (or concurrently) without altering the principles of the present disclosure. Further, although each of the embodiments is described above as having certain features, any one or more of those features described with respect to any embodiment of the disclosure can be implemented in

and/or combined with features of any of the other embodiments, even if that combination is not explicitly described. In other words, the described embodiments are not mutually exclusive, and permutations of one or more embodiments with one another remain within the scope of this disclosure.

5 **[0093]** Spatial and functional relationships between elements (for example, between modules, circuit elements, semiconductor layers, etc.) are described using various terms, including “connected,” “engaged,” “coupled,” “adjacent,” “next to,” “on top of,” “above,” “below,” and “disposed.” Unless explicitly described as being “direct,” when a relationship between first and second elements is described in the above disclosure,
10 that relationship can be a direct relationship where no other intervening elements are present between the first and second elements, but can also be an indirect relationship where one or more intervening elements are present (either spatially or functionally) between the first and second elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A OR B OR C), using a non-exclusive
15 logical OR, and should not be construed to mean “at least one of A, at least one of B, and at least one of C.”

[0094] In some implementations, a controller is part of a system, which may be part of the above-described examples. Such systems can comprise semiconductor processing equipment, including a processing tool or tools, chamber or chambers, a platform, or
20 platforms for processing, and/or specific processing components (a wafer pedestal, a gas flow system, etc.). These systems may be integrated with electronics for controlling their operation before, during, and after processing of a semiconductor wafer or substrate. The electronics may be referred to as the “controller,” which may control various components or subparts of the system or systems. The controller, depending
25 on the processing requirements and/or the type of system, may be programmed to control any of the processes disclosed herein, including the delivery of processing gases, temperature settings (e.g., heating and/or cooling), pressure settings, vacuum settings, power settings, radio frequency (RF) generator settings, RF matching circuit settings, frequency settings, flow rate settings, fluid delivery settings, positional and
30 operation settings, wafer transfers into and out of a tool and other transfer tools and/or load locks connected to or interfaced with a specific system.

[0095] Broadly speaking, the controller may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue

instructions, control operation, enable cleaning operations, enable endpoint measurements, and the like. The integrated circuits may include chips in the form of firmware that store program instructions, digital signal processors (DSPs), chips defined as application specific integrated circuits (ASICs), and/or one or more microprocessors, or microcontrollers that execute program instructions (e.g., software). Program instructions may be instructions communicated to the controller in the form of various individual settings (or program files), defining operational parameters for carrying out a particular process on or for a semiconductor wafer or to a system. The operational parameters may, in some embodiments, be part of a recipe defined by process engineers to accomplish one or more processing steps during the fabrication of one or more layers, materials, metals, oxides, silicon, silicon dioxide, surfaces, circuits, and/or dies of a wafer.

[0096] The controller, in some implementations, may be a part of or coupled to a computer that is integrated with the system, coupled to the system, otherwise networked to the system, or a combination thereof. For example, the controller may be in the “cloud” or all or a part of a fab host computer system, which can allow for remote access of the wafer processing. The computer may enable remote access to the system to monitor current progress of fabrication operations, examine a history of past fabrication operations, examine trends or performance metrics from a plurality of fabrication operations, to change parameters of current processing, to set processing steps to follow a current processing, or to start a new process. In some examples, a remote computer (e.g., a server) can provide process recipes to a system over a network, which may include a local network or the Internet. The remote computer may include a user interface that enables entry or programming of parameters and/or settings, which are then communicated to the system from the remote computer. In some examples, the controller receives instructions in the form of data, which specify parameters for each of the processing steps to be performed during one or more operations. It should be understood that the parameters may be specific to the type of process to be performed and the type of tool that the controller is configured to interface with or control. Thus, as described above, the controller may be distributed, such as by comprising one or more discrete controllers that are networked together and working towards a common purpose, such as the processes and controls described herein. An example of a distributed controller for such purposes would be one or more integrated circuits on a chamber in communication with one or more integrated circuits located

remotely (such as at the platform level or as part of a remote computer) that combine to control a process on the chamber.

[0097] Without limitation, example systems may include a plasma etch chamber or module, a deposition chamber or module, a spin-rinse chamber or module, a metal
5 plating chamber or module, a clean chamber or module, a bevel edge etch chamber or module, a physical vapor deposition (PVD) chamber or module, a chemical vapor deposition (CVD) chamber or module, an atomic layer deposition (ALD) chamber or module, an atomic layer etch (ALE) chamber or module, an ion implantation chamber or module, a track chamber or module, and any other semiconductor processing systems
10 that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

[0098] As noted above, depending on the process step or steps to be performed by the tool, the controller might communicate with one or more of other tool circuits or modules, other tool components, cluster tools, other tool interfaces, adjacent tools,
15 neighboring tools, tools located throughout a factory, a main computer, another controller, or tools used in material transport that bring containers of wafers to and from tool locations and/or load ports in a semiconductor manufacturing factory.

CLAIMS

What is claimed is:

1. An end effector for a substrate processing system, comprising:
a body including:
 - 5 a first body portion configured to connect to a wrist of a robot;
a second body portion extending from the first body portion and including
a first arm, a second arm, and a slot between the first arm and the second arm; and
a plurality of contact pads comprising:
 - N contact pads arranged on the second body portion adjacent to the first
10 body portion, where N is an integer greater than two;
M contact pads arranged on distal ends of the first arm and the second
arm, respectively, where M is an integer greater than one;
P contact pads, where P is an integer greater than one; and
Q contact pads, where Q is an integer greater than one,
15 wherein the P contact pads and the Q contact pads are located on the
first arm and the second arm between the N contact pads and the M contact pads.
2. The end effector of claim 1, wherein the body includes (N+M+P+Q) cavities for
receiving the plurality of contact pads.
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3. The end effector of claim 1, wherein the N contact pads, the M contact pads, the
P contact pads, and the Q contact pads are made of elastomer.
4. The end effector of claim 1, wherein the end effector is made of one or more
25 materials comprising alumina (Al_2O_3), sapphire (Al_2O_3), silicon carbide (SiC), silicon
nitride (SiN), aluminum nitride (AlN), graphite, and molybdenum (Mo).
5. The end effector of claim 1, wherein the end effector is made of alumina (Al_2O_3).
- 30 6. The end effector of claim 1, wherein $N = 3$ and wherein the N contact pads are
spaced evenly from one another on the second body portion.

7. The end effector of claim 1, wherein $N = 4$ and wherein the N contact pads are spaced evenly from one another on the second body portion.
8. The end effector of claim 1, wherein the end effector has a thickness in a range
5 from 0.070" to 0.090".
9. The end effector of claim 1, wherein a height of the N contact pads and the M contact pads is greater than a height of the P contact pads and the Q contact pads.
- 10 10. The end effector of claim 1, wherein:
a height of the N contact pads and the M contact pads is in range from 0.015" to 0.060"; and
the height of the P contact pads and the Q contact pads is in range from 0.010" to 0.040", and
15 the height of the N contact pads and the M contact pads is greater than the height of the P contact pads and the Q contact pads.
11. The end effector of claim 1, wherein the P contact pads and the Q contact pads are arranged along a circle having a first radius and the N contact pads and the M
20 contact pads are arranged along a circle having a second radius that is greater than the first radius.
12. The end effector of claim 11, wherein a third radius of a substrate supported by the end effector is greater than the first radius and the second radius.
- 25 13. The end effector of claim 1, wherein the first body portion has a first thickness, and the second body portion has a second thickness less than the first thickness.

14. A substrate delivery system for a substrate processing chamber, comprising:
a robot including a wrist;
an end effector connected to the wrist and including a body, a first arm and a second arm extending from the body, and a plurality of contact pads configured to support a substrate above the body;
a substrate support;
lift pins configured to extend above the substrate support and to retract;
a processing chamber including a chamber port; and
a controller configured to perform a first transfer sequence to deliver the substrate onto the substrate support, wherein the first transfer sequence includes:
causing the robot to load the substrate onto the end effector;
with the lift pins retracted, causing the robot to pass the substrate and the end effector through the chamber port to a location above the substrate support;
causing the lift pins to extend;
causing the end effector to lower the substrate onto the lift pins; and
causing the robot to withdraw the end effector through the chamber port.
15. The substrate delivery system of claim 14, wherein:
the processing chamber further includes a chamber liner including a chamber liner slot,
the controller is configured to:
pass the substrate and the end effector through the chamber port and the chamber liner slot to the location above the substrate support; and
remove the end effector through the chamber port and the chamber liner slot.
16. The substrate delivery system of claim 14, wherein the controller is further configured to perform a second transfer sequence to retrieve a substrate from the substrate support, wherein the second transfer sequence includes:
causing the lift pins to extend to raise the substrate above the substrate support;
causing the robot to move the end effector between the substrate support and the substrate;
causing the robot to raise the end effector;
causing the lift pins to be lowered; and

causing the robot to remove the substrate through the chamber port.

17. The substrate delivery system of claim 16, wherein the body of the end effector includes:

- 5 a first body portion configured to connect to the wrist; and
 a second body portion extending from the first body portion and including the first arm, the second arm, and a slot between the first arm and the second arm,

 wherein the plurality of contact pads include:

- N contact pads arranged on the second body portion adjacent to the first
10 body portion, where N is an integer greater than two;

 M contact pads arranged on distal ends of the first arm and the second arm, respectively, where M is an integer greater than one;

 P contact pads, where P is an integer greater than one; and

 Q contact pads, where Q is an integer greater than one,

- 15 wherein the P contact pads and the Q contact pads are located on the first arm and the second arm between the N contact pads and the M contact pads.

18. The substrate delivery system of claim 17, wherein the body includes (N+M+P+Q) cavities for receiving the contact pads.

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19. The substrate delivery system of claim 17, wherein the N contact pads, the M contact pads, the P contact pads, and the Q contact pads are made of elastomer.

20. The substrate delivery system of claim 17, wherein the end effector is made of
25 one or more materials comprising of alumina (Al_2O_3), sapphire (Al_2O_3), silicon carbide (SiC), silicon nitride (SiN), aluminum nitride (AlN), graphite, and molybdenum (Mo).

21. The substrate delivery system of claim 17, wherein the end effector is made of alumina (Al_2O_3).

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22. The substrate delivery system of claim 17, wherein $N = 3$ and wherein the N contact pads are spaced evenly from one another on the second body portion.

23. The substrate delivery system of claim 17, wherein $N = 4$ and wherein the N contact pads are spaced evenly from one another on the second body portion.

24. The substrate delivery system of claim 17, wherein the end effector has a
5 thickness in a range from 0.070" to 0.090".

25. The substrate delivery system of claim 17, wherein a height of the N contact pads and the M contact pads is greater than a height of the P contact pads and the Q contact pads.

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26. The substrate delivery system of claim 17, wherein:
a height of the N contact pads and the M contact pads is in range from 0.015" to 0.060"; and

15 the height of the P contact pads and the Q contact pads is in range from 0.010" to 0.040", and

the height of the N contact pads and the M contact pads is greater than the height of the P contact pads and the Q contact pads.

27. The substrate delivery system of claim 17, wherein the P contact pads and the Q
20 contact pads are arranged along a circle having a first radius and the N contact pads and the M contact pads are arranged along a circle having a second radius that is greater than the first radius.

28. The substrate delivery system of claim 27, wherein a third radius of a substrate
25 supported by the end effector is greater than the first radius and the second radius.

29. The substrate delivery system of claim 17, wherein the first body portion has a first thickness, and the second body portion has a second thickness less than the first thickness.